Polarization of electromagnetic radiation a resource for predicting soil moisture

Sam Nwaneri[1], and Dr. Wubishet Tadasse

[1]NASA Center for Hydrology, Soil Climatology, and Remote Sensing (HSCaRS). Dept. of Plant and Soil Science.
P.O. Box 1208, Alabama A&M University, Normal, AL 35762
[1](Tel: 256-650-0238, 256-372-4252, Fax: 256-851-5076. E-mail: integer7@netzero.net), Wtadesse@aamu.edu

Abstract: This paper discusses the prediction model of soil moisture content (SMC). The purpose is to model SMC with respect to use segregation (*useg*), temperature, and the intensity of local solar radiation that causes polarization of electromagnetic radiation (EMR). The objectives include using basic laws of radiation to assess how radiation intimately interacts with matter. The methodology consists of four method spaces dealing with: polarization of dielectric medium; hysteresis accounting for the rhythms of polarization and relaxation time; validation of temperature effects on polarization and medium susceptibility; and the nesting of the medium complex dielectric permittivity to its void capacity (nεv) or the Boolean Space (BS). Solar radiation impinging on the soil—a dielectric medium, is a form of EMR that generates mechanisms of charge displacement (polarizations). The study found that BS approach can adequately be a predictor resource under the ideal temperature.

1. INTRODUCTION

Agriculture depends on soil water; about 0.005% of world's water, and five times the atmosphere water. [5] pointed out that the variations of annual net radiation and temperature, between the equator and the poles reflects on water needs in these regions, and gives a clue that EMR could be a resource in predicting SMC.

In hygroscopic materials like wood, moisture content shows as "water vapor in air spaces, cell cavities, capillarity water in the cell cavities," and bound water; "water molecules bound to the hydroxyl group of the cellulose in the cell wall."…and "when wood is not in contact with water" almost all the moisture content is bound water, ranging from "3 to 30 % of the dry weight" [13]. In most bulk materials like soil, the complex dielectric permittivity gives the mechanical properties of SMC. For example, the real value (ε') of the dielectric permittivity reflects on the soil free water while the imaginary part (ε") relates to the medium bound water. Other soil mechanisms relative to moisture content are density, electric, magnetic and thermal, phenomena.

Density mechanisms come in three parts; impregnated (wet), unimpregnated (dry) and theoretical/specific or relative. Density relates to properties such as porosity, which is a media self-lubricator through spongy pores and capillary connectivity [14]. Permeability is a check on porosity Electrical resistivity and ultrasonic velocity almost has linear relations with density but not as the relative density increases. These dynamic properties exhibit exponential relations, e.g. the penetration of EMR into the soil. [14] noted that ultrasonic detection of density is better than using the media permeability, however, the sensitivity associated with media permeability implicates desirable interferences with the media particle and pore sizes, and pore morphology [14]. The electrical resistivity of soils also relates to the media porosity.

Magnetic behavior that relates to SMC points to permeability as a function of density for fixed/varying magnetic field. Though, this behavior is frequency-dependent, the impinging EMR produces the magnetic field, whose sensitivity is "the effect of pores on reversible displacement of domain boundaries" [14]. This relation implies that permeability in soil regions with low impinging EMR has a linear relationship with density. However, permeability may not be a better predictor of density or porosity rather, the ε_o and μ_o are respectively intimate with light, and vary in time, as nomenclatures of light, in electromagnetic wave (EMW) that propagate at the speed of light $1/\sqrt{(\varepsilon_o\mu_o)}$ [2] [11][14], may serve better purpose.

Particle collision resulting from electromagnetic activities gives rise to thermal conditions. These physical properties account for the rhythms and lubrication of the soil systems. Thus far, the concern for, and the complexity of the small quantity of soil water creates a consideration that limit this study to few ideal conditions--within the first one meter (3 feet) of soil depth, and also accept the ratio of air to water in the soil to be 1:1 [1].

II. PURPOSE OF STUDY

The aim of this study is to point out that the many approaches to soil moisture measurements are different from SMC prediction, and thus to help contribute to the development of a soil moisture predictor resource that depends on ***useg***, solar radiation, dielectric permittivity and thermal agitation. The ***useg*** of soil implies the different needs and uses of soil types to include: structural support in civil engineering, farming, foresters, and other soil scientists. These categories of use evaluate soil moisture samples by applying different thermal phenomena in moisture extraction such as pounds per cubic inch or oven dry…and consequently get different results.

III. DATA COLLECTION AND METHODOLOGY

Data were collected in June 22 through 26 of 2003, from eight counties in Alabama by the Department of Plant and Soil Science, Alabama A&M University, during the Soil Moisture Experiment of 2003 (SMEX03). The gravimetric analysis was done by SMEX03 to determine the percentage of SMC (by mass). The sample framework was agricultural farmlands covering over 119792.54 hectares (463 miles^2) and each county served as a sample unit. Each of the eight counties has at least four sampling sites where data were collected on different days.

Soil samples were collected within 3 inches depth of bare soil with 3 inches deep metal cups. The SMEX03 did the gravimetric analysis and determined the percentage of moisture content by mass and tabulated the results with meteorological conditions observed during collection. The study evaluated and grouped the data, and used it to investigate the influence of local solar radiation on SMC during the period of observation.

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The intensity of solar radiation across the sample frame were augmented in time into five different partitions to include, sunny, cloudy, dry, wet, moistened and shaded. To allow for enough solar intensity, the earliest and latest collection times approached 11:00 am and 3:00 pm respectively. The land uses of the sites were suppressed or used as a constant. The second augmentation was site specific, including 10 consecutive samples from each selected site. Furthermore, the second augmentation was used to evaluate the range of SMC during the period, had 3 meteorological partitions; **sunny**/clouds/**dry**; blind search, and sun/**cloudy**/**moist**. The partitions of the field data were plotted on Microsoft Excel and compared. (See Figures 1- 2).

The relationships between data, soil moisture and radiation were evaluated with respect to dielectric polarization involving: space charge polarization, polarization by dipole alignment, ionic polarization and electronic polarization. These polarizations are frequency dependent and may overlap [6]. The dipoles of the polarized medium act as micro harmonic arms (MHA). Statistically, the study associated a Boolean space (BS)--heat dissipation in volume elements, with each MHA to create fractional volume f = nv (number of particle (n) per unit volume (v). The presence of the BS is expressed as a probability **p**, and the absence as **q** (q = 1-p) Hence fractional volumes f and 1-f exist, and defined "Self-absorbing Markov media" respectively ($SaMm_1$) at p = 1 ≡ f =1 (no scattering and no absorption). The state n-1 before $SaMm_1$ defines a dense medium, and a probability of q = 1, theoretically implies no particle-space. Thus q =1 is another $SaMm_0$, but the n-1 state before $SaMm_0$ defines a sparse distribution of particles, such that the particle state is synonymous to its bounding surface and hence no scattering or absorption [10] [12]. The domain between $SaMm_1$ and $SaMm_0$ defines all types of media encountered in the soil sampling experiments.

Some attributes of radiation were suppressed, such as; emissivity, brightness temperature, reflectivity, media mass…but the account for solar radiation at the speed of light:

$c = f\lambda\sqrt{\varepsilon}$ *Eq.1*

shows the intimacy of the dielectric permittivity (ε) in equation 1 with frequency (f), wavelength (λ) of the EMR and how they are modified by media in the skin depth phenomenon (depth of relative penetration-∂) [13] [16]. The ε changes with probabilities that define any media between the SaMm. The order of temperature as image of heat whenever water changes state [8], was applied as ideal operator on polarization and medium susceptibility.

The evaluation of relaxation time of polarized media was used to bridge the data and media properties such as the ε due to the fact that it exhibits immersed EMR attenuation properties such as: the relations of T_b and observation angle; T_b and frequency; T_b and nadir viewing angle (scatter-induced, bright/block emissions); frequency and albedos; and frequency and reflectivity [10]. These relations show media and EMR relationships, which are obvious parameters affecting some attributes of the relaxation time.

V. FINDINGS

The first data group partitions showed that SMC decreased with increased solar radiation (sunny and dry); the effects of shade did not change this condition, and SMC increased with low local solar radiation (cloudy and wet/moist). The second group partition showed relatively large range of moisture content (about 4 to 37%) for wet/moist, and (about 5 to 28%) for sunny/dry meteorological conditions (See Figures 3 -- 4). These conditions revealed inverse relations between SMC and the local solar radiation. The fact that EMR attenuates exponential in media such as soil, may well propose a logarithmic growth for the SMC. The study emphases the nesting of the media ε to the volume of SMC and also capitalized on the inverse relation observed. (See Figures 5 – 6)[3] [4].

The dielectric micro-polarizations considered with respect to the data are frequency dependent to include: space charge polarization, polarization by dipole alignment, ionic polarization and electronic polarization. These polarization phenomena may overlap due to the stages in which they occur, such as the elementary, molecular and atomic surfaces of a particle [6]

Polar media polarizes due to the permanent geometry of the charged molecular particles and the aligning force of the applied electric field, for example water. Nonpolar media polarization depends on induced molecular dipole moment. The electronic polarization is virtually the displacement of negative electron cloud from the positive atomic nucleus towards the applied electric field [6].

The rhythms of micro (molecular) and macro polarizations showed different relaxation times due to the relationship between relaxation frequency and molecule size: Debye's theory sets the complex dielectric permittivity (ε' + ε") as a function of frequency in a way to approach this relationship. The macroscopic-polarization of the medium revealed that the MHA or permanent and induced microscopic dipoles movement (rotational) are due to the applied electric force, where friction and viscosity accounted for the angular velocity of the dipole movement; $\tau = 1/\omega_\tau = \zeta/2kT = 4r^3\xi/kT$ *Eq 2*

(τ = macroscopic relaxation time, ω_τ. = angular velocity, r = radius of molecule, ζ = friction, ξ = viscosity, k = constant and T = temperature)[6]. When this movement is hindered by intermolecular bonds, hysteresis between applied field and polarization results [6] [9] [7].

1. Polarization: As the size of the BS radius defines the dipoles, each individual dipole moment **p** acquires a volume element the BS, which converts to macro volume V_o. The average dipole moment per unit volume of dielectric is the ratio of the sum of dipole moments P_s to the macro volume V_o (P_s/V_o). This ratio is the polarization P resulting from microscopic polarization vector $\mathbf{P}_v$ [2], thus: $\mathbf{P}_v = \lim (P_s/V_o) = dp/dv(V_x \rightarrow 0)$ E*q.4*

A microscopic volume (Vx) is an imprint on a BS template. The expression Vx → 0 means that the volume imprints on the templates are so small but not practically zero, and could be large enough to contain some good number of molecules of the element. The imprints of the template are the acquired dipole moments that define dipolar rotation, intermolecular friction and hysteresis between the applied field and the induced electric response. A good number of the volume elements limit high loss in dielectric materials. Thermal runaway and the creep zone were emphasized as consequences of ε [6] [9].

2. Micro polarization: In electronic polarization, an area **A,** with nAP_s molecules, (n = number of molecules per unit volume) as the electric field increases with the spatial separation of the opposite charges within the dielectric. This type of polarization is directly proportional to the electric susceptibility (χ) and the dielectric constant of the medium and is represented as: $P = \chi\varepsilon E$ *Eq.5*

(E = external electric filed). The spatial separation implies low thermal agitation due to reduced possibility of particle collisions. [($\chi > 0$), then $\varepsilon = (1+\chi)\varepsilon_o$] *Eq.6,* then ε is always greater than zero. The applied field is directly related to polarization, which is inversely related to the effective temperature, as shown in the equations below:

$\mathbf{P = np^2E/3kT = \chi\varepsilon_o E}$ *Eq.7*

It follows that $\boldsymbol{\chi = np^2/3\varepsilon_o kT}$ *Eq.8*

Note that inverse relation between temperature and **χ** is applicable at ideal thermal agitation [9] [10].

The relative penetration of radiation (Skin depth) is that depth ∂, in a dielectric medium where the applied electric field density, responsible for polarization, exponentially decreases to about 37% (e^{-1}), at a time constant, (τ). Radiant flux attenuation in a uniform medium is an exponential order [6].

IV. RESULTS AND CONCLUSION

According to The USDA's soil textural triangle, different soils relate by particle size [1]. However, the percent of soil moisture derived from the SMEX03 was equivalent to measuring SMC of a suspension involving the dielectric permittivity of the liquid ε_p and the solid ε_q. [8] emphasized the nesting of the complex dielectric permittivity of suspension ε_s in terms of relative volumes of the liquid as follows: $\varepsilon_s^{1/2} = V_1\varepsilon_p^{1/2} + (1-V_1)\varepsilon_q^{1/2}$ *Eq 10*

(Subscript 1 is for the liquid, 2 for the solid and V_1 = relative volume of liquid. Since the SMEX03 SMC (M) was derived in percentage grams of specific mass, thus,

M = (wetW – dryW/dryW-canW) *Eq.11*

$Ms = 100m_1/(m_1+m_2)$ of a suspension, and *Eq.12*

$V_1 = Mg_2/(100\text{-}M)g_1 + Mg_2)$ [8] *Eq.13*

(g = the respective specific masses, m_2 = dry weight of soil, Ms = M as volume of a suspension instead of oven dry). Then $Ms = \rho_l V_l/(\rho_l V_l + \rho_s V_s)$, and as $\rho_s V_s$ tends to 1, the minimum value for Ms is 0.5. The assumption that $\rho_s V_s$ tends to 1 relates to the definition of suspension and $SaMm_0$ (homogeneous mixture of liquid and minute solid particles; ρ = density). Equations 11 to 13 serve as SMC predictors if at least two of the variables are known; and only if they are nested operations of the media permittivity, like in Equation 10.

The method space as used in the methodology can convert to modules development (self functioning inventory operator) whose availability and reliability is independent of other modules. It is also observed that most measurements in the study involved attenuation, which can be configured into some types of Low Pass Filter that runs on MathLab platforms to create a breadboard instrumental experiment with reasonable cost/benefit ratio. Such devices can measure SMC and also predict SMC from virtually dry and wet soils respectively. In this way, prediction of SMC can become a policy instrument.

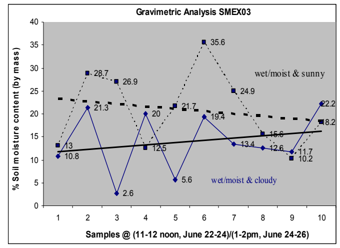

Figure 1. %of SMC (wet/cloudy)

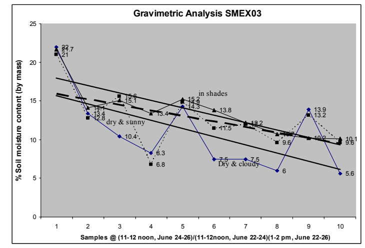

Figure 2. % of SMC (Dry/Sunny/shaded)

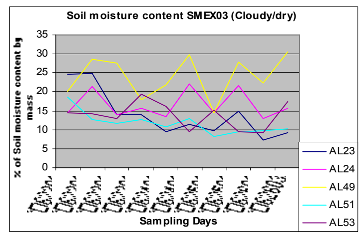

Figure 3. Range of SMC

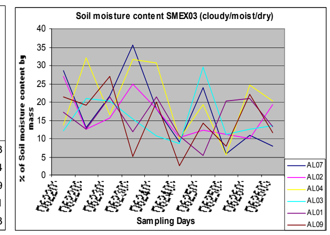

Figure 4. Range of SMC

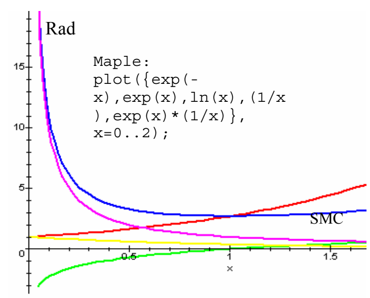

Figure 5. Rad./SMC relations

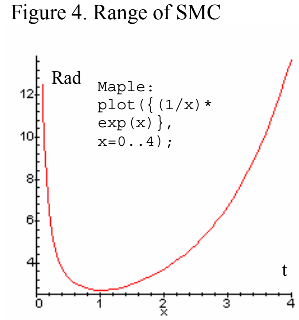

Figure 6 order of Temperature (t)

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